

Corrosion Protection and Dissimilar Material Joining for Next-Generation Lightweight Vehicles

Donald J. Spinella – Principal Investigator

Arconic Technology Center

June 3, 2020

Project ID: MAT133



ARCONIC



"This presentation does not contain any proprietary, confidential, or otherwise restricted information."

Overview

Timeline:

- Start Date: October 1, 2016
- End Date: September 30, 2020
- 80% complete

Budget:

- Total project funding: \$2,395,295
 - Govt. share: \$1,764,330
 - Partner share: \$630,965
- Funding in FY2019: \$253,778
- Funding for FY2020: \$380,667

Barriers:

- Combinations of dissimilar materials with fasteners can cause galvanic corrosion.
- Joining of multi-material systems requires new technologies that may require billions in capital.
- Many existing fasteners are incompatible with UHSS/AHSS or require additional process steps.*

Partners:

- Arconic Corporation – Lead
- Honda R&D Americas, LLC
- The Ohio State University

Approach / Relevance

Project Objectives:

- Develop weld process parameters and produce joints between Al, AHSS, and CFRP to establish confidence in RSR process robustness.
- Evaluate extent of galvanic corrosion and identify corrosion mitigation strategies.
- Demonstrate RSR implementation on a robotic system exploring process boundaries such as joint gaps, angularity, adhesives, and flange width variations.

Impact:

- Provide high performance multi-material joining with the existing RSW infrastructure and knowledge base, offsetting billions in capital other technologies would require.
- Increase flexibility of the existing infrastructure by allowing spot welding of like materials in sequence along with dissimilar material joining by simply not feeding a rivet to the tips.
- Enable an additional 10-20% weight reduction over high strength steel-only designs, providing a 1.5 - 3% total improvement in fuel efficiency for vehicles that incorporate RSR for multi-material joining.

Milestones

	BP1					BP2				BP3							
	2016	2017				2018				2019				2020			
Milestones and Go / No-Go points	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Define preliminary material & part and testing requirements	100%																
Steel RSR piloted & self-piloted weld process developed		100%															
Al RSR piloted weld process developed		100%															
Rivet mat'l/coating assement for Al to St & CFRP		100%															
Mechanical property assessment for Steel RSR				100%													
Corrosion assessment for Baseline SPR and FDS joints				100%													
Go/No Go: Steel RSR Joints meet targets					100%												
Al to Steel RSR piloted weld process developed						100%											
Al to CFRP RSR piloted weld process developed							100%										
Corrosion Testing Completed for All RSR Configurations						100%											
Steel & Al RSR production process condition limits established								100%									
Go/No Go: Establish production condition limits											100%						
RSR feed system repeatability established								100%									
Go/No Go: Establish feed system repeatability											100%						
Determine prod galvanic corrosion mitigation strategies										75%	→						
RSR pilot cell complete											100%						
Manufacture demonstrator parts and assemblies										50%	→						
Test demonstrator assemblies																	
Final Reporting																	

Technical Accomplishments and Progress

Test Plan Matrix for Preliminary EL, Mechanical, and Corrosion Test

Joint Stackup Description							Team Member Test Type			Budget Period
Rivet	Pilot	Top	Adh*	Mid	Adh*	Bottom	Arconic	Honda	OSU	
St RSR	Y	AURAL2 3.0mm	Y			JAC 980 1.2mm	E	C	C	1
	Y	AURAL2 3.0mm	N			JAC 980 1.2mm	M		C	1
	Y	AURAL2 3.0mm	Y	JAC 980 1.2mm	N	JAC 980 1.2mm	E	C	C	1
	Y	AURAL2 3.0mm	N	JAC 980 1.2mm	N	JAC 980 1.2mm	M		C	1
	N	MMHF-T4 1.0mm	Y	USIBOR 1500 1.2mm	Y	JAC 980 1.2mm	E	C	C	1
	N	MMHF-T4 1.0mm	N	USIBOR 1500 1.2mm	N	JAC 980 1.2mm	M		C	1
	Y	AA6013-T4 2.0mm	N			JAC 980 1.2mm	M		C	1
	Y	AA5754-O 2.0mm	N			JAC 980 1.2mm	M		C	1
	Y	AA7055-T76 2.0mm	N			JAC 980 1.2mm	M		C	1
	Y	AA6013-T4 2.0mm	N			JAC 590 1.2mm	M		C	1
AI RSR	Y	JAC 980 1.2mm	Y			AURAL2 3.0mm	E	C	C	2
	Y	JAC 980 1.2mm	N			AURAL2 3.0mm	M		C	2
	Y	JAC 980 1.2mm	N	JAC 980 1.2mm	Y	AURAL2 3.0mm	E	C	C	2
	Y	JAC 980 1.2mm	N	JAC 980 1.2mm	N	AURAL2 3.0mm	M		C	2
	Y	JAC 980 1.2mm	Y	USIBOR 1500 1.2mm	Y	MMHF-T4 1.0mm	E	C	C	2
	Y	JAC 980 1.2mm	N	USIBOR 1500 1.2mm	N	MMHF-T4 1.0mm	M		C	2
	Y	Semi-Iso CFRP 4.0mm	N			AA6013-T4 2.0mm	M		C	2
	Y	Semi-Iso CFRP 4.0mm	N			AA6013-T4 3.0mm	M		C	2
	Y	Semi-Iso CFRP 4.0mm	Y			AA6013-T4 3.0mm	E	C	C	2
St SPR Baseline	N	JAC 590 1.2mm	Y			AA6013-T4 2mm	M		C	1
	N	JAC 590 1.2mm	N			AA6013-T4 2mm	M		C	1
St FDS Baseline	Y	JAC 980 1.2mm	Y			AA7055-T76 2mm	M		C	1
	Y	JAC 980 1.2mm	N			AA7055-T76 2mm	M		C	1
Adh* - Adhesive between sheets				Test Code		Electrode Life	Mechanical Testing		Corrosion	

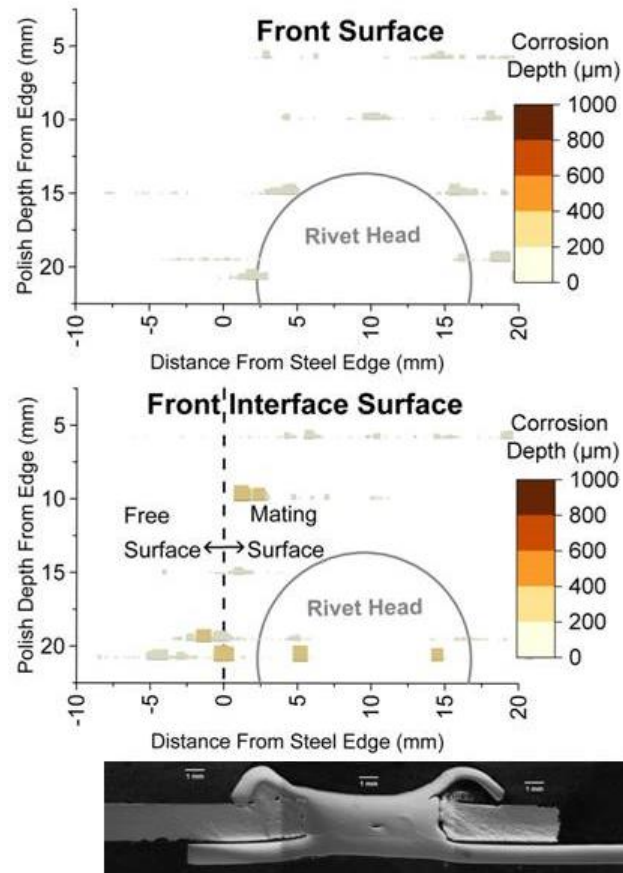


BP3 demonstrators are based from this joint stackup

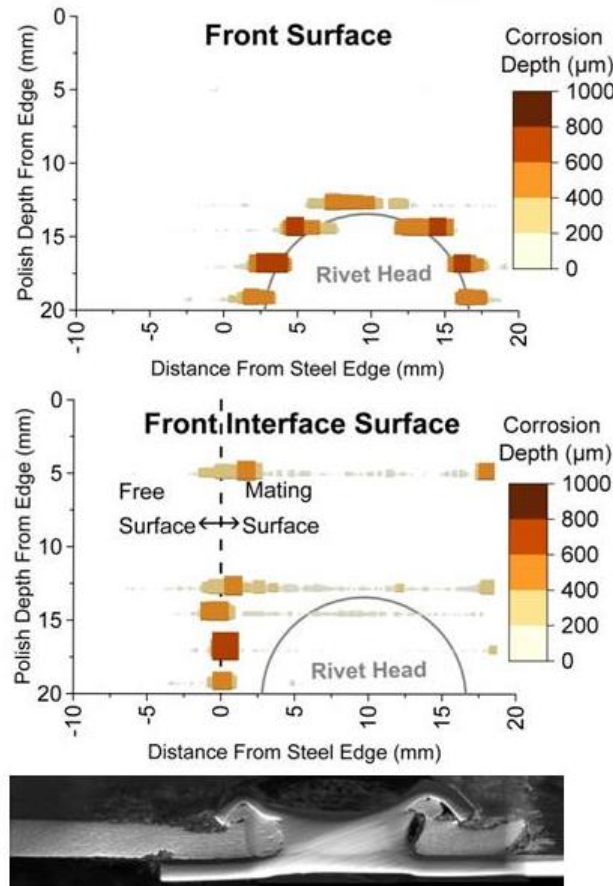
Technical Accomplishments Continued

AA6013-T4 joined to 980MPa steel via RSR after 32.4 days exposure

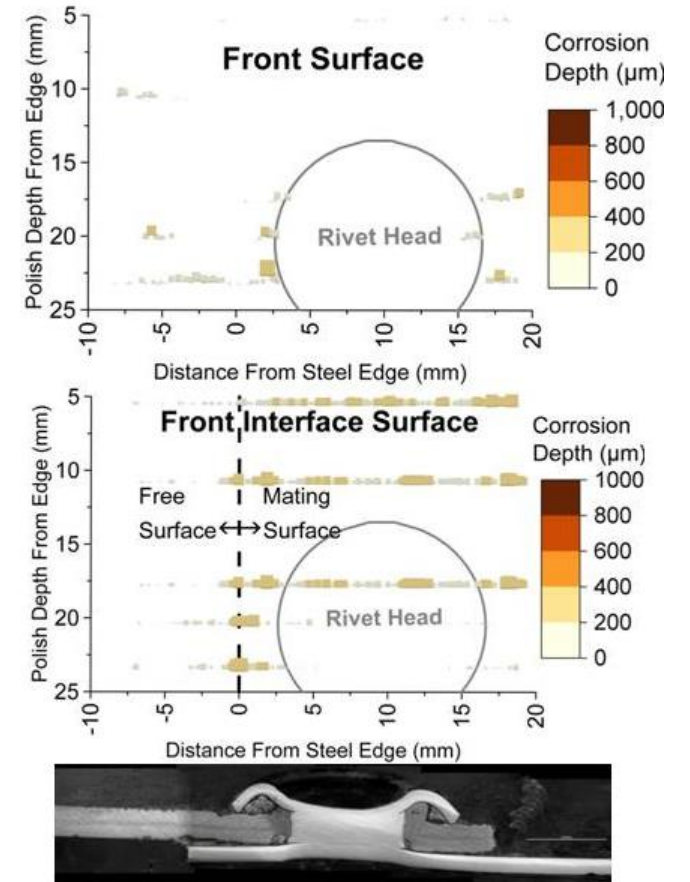
ASTM B117



ASTM G85-A2



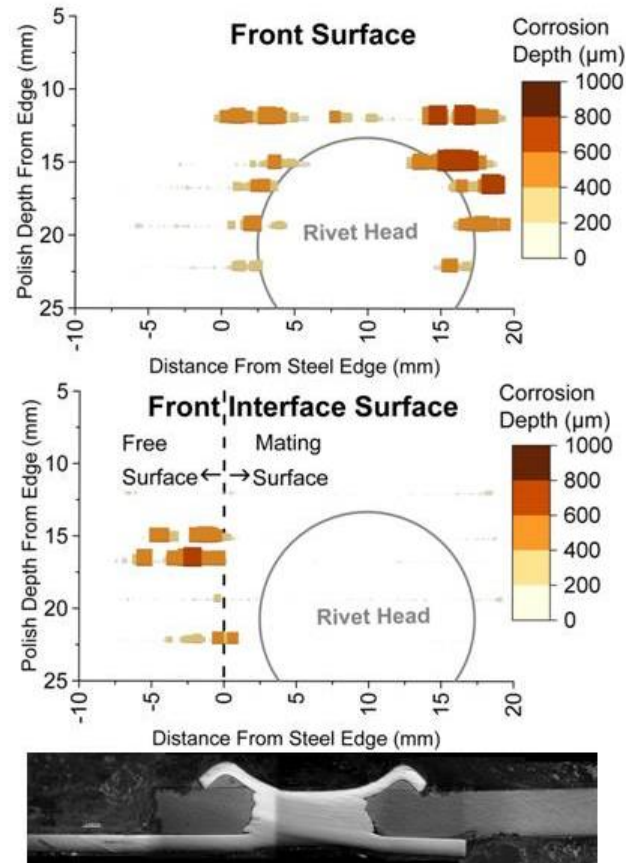
CCT-1



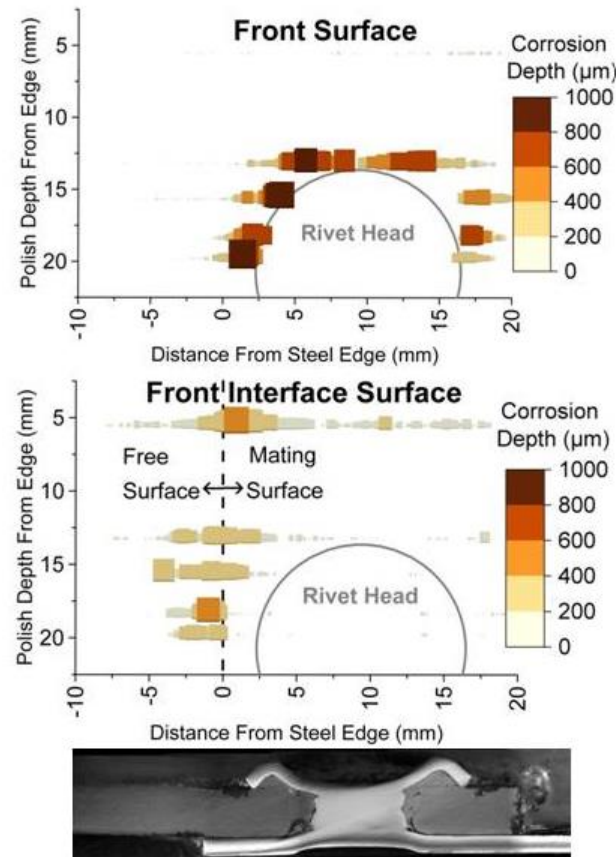
Technical Accomplishments Continued

Aural2 casting joined to 980MPa steel via RSR after 32.4 days exposure

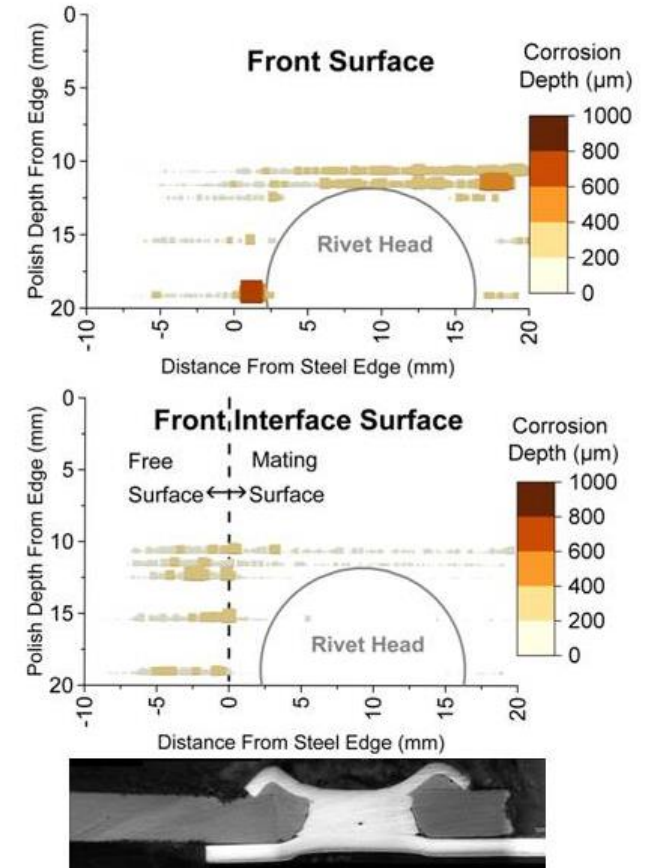
ASTM B117



ASTM G85-A2



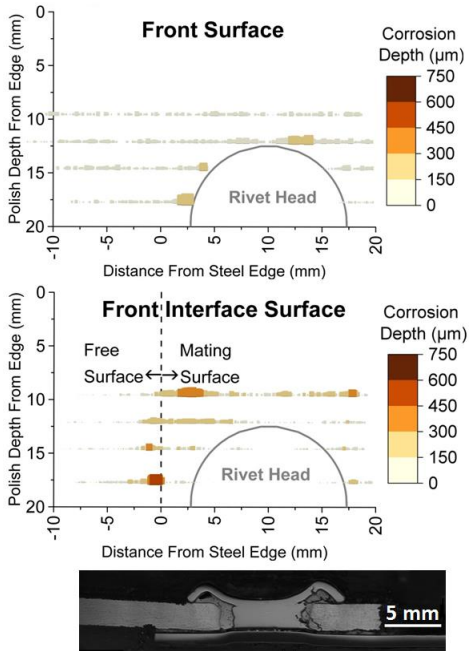
CCT-1



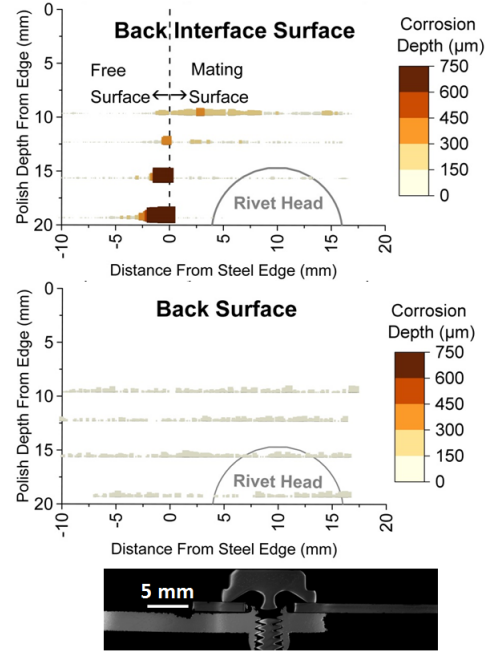
Technical Accomplishments Continued

Effect of sample orientation in test chamber after 21 days exposure of ASTM G85-A2

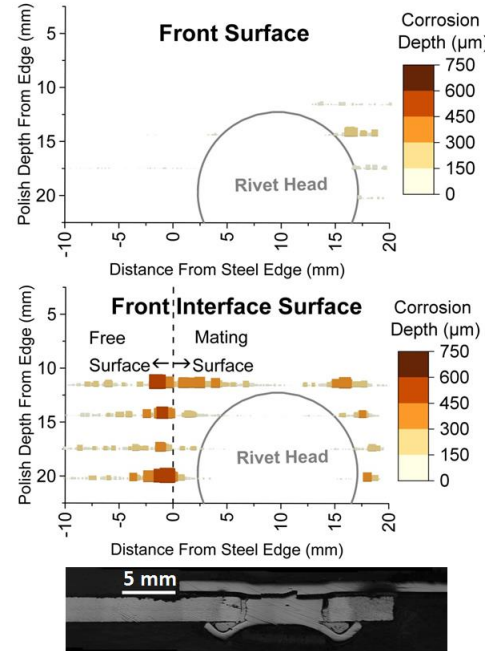
RSR 7055
Steel Down



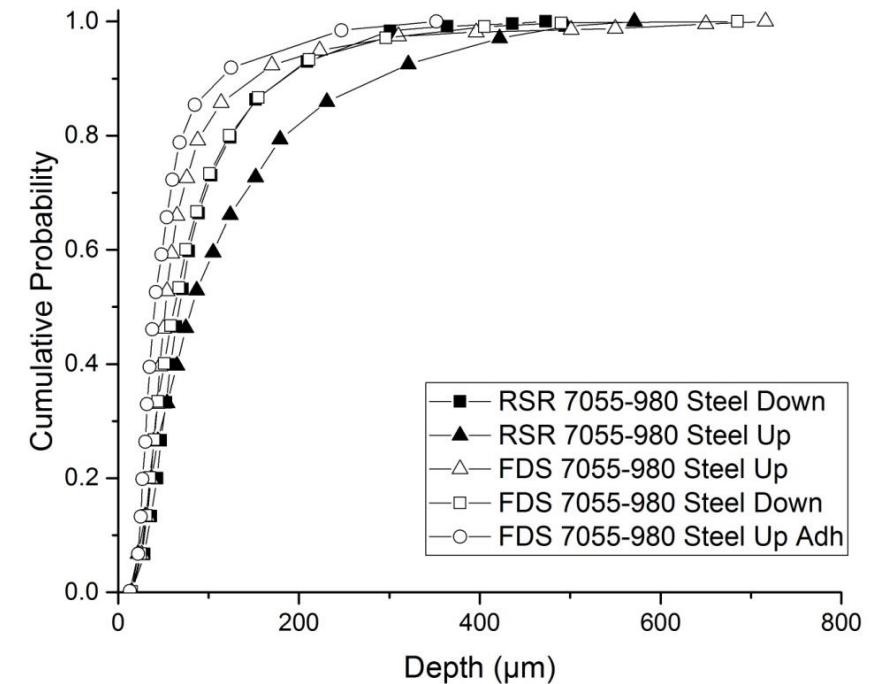
FDS 7055
Steel Up



RSR 7055
Steel Up



CCT-1



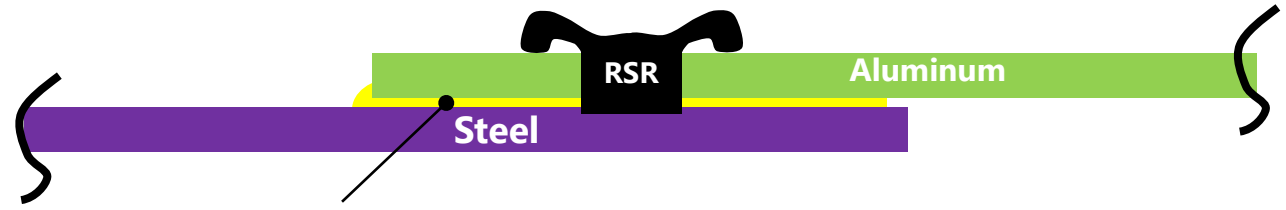
Sample orientation must be considered when comparing various joining combinations

Galvanic Corrosion Mitigation Techniques

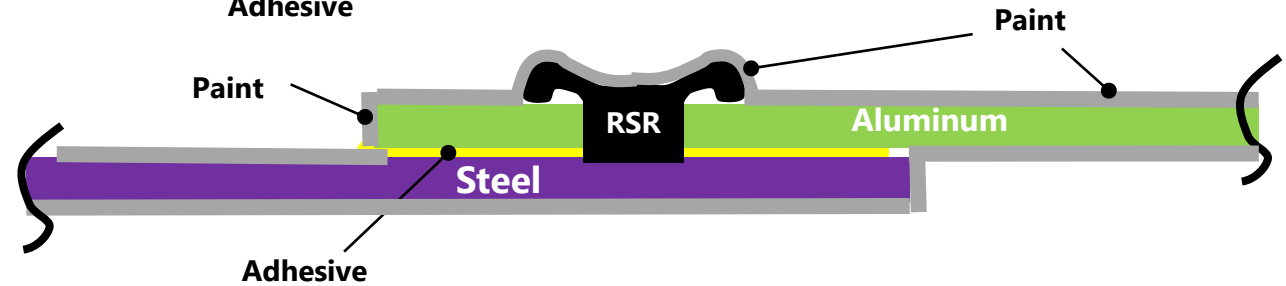
Four types of corrosion mitigation techniques evaluated for both TSS and CTS joint types

E-coat applied to all samples 1-4 after joined

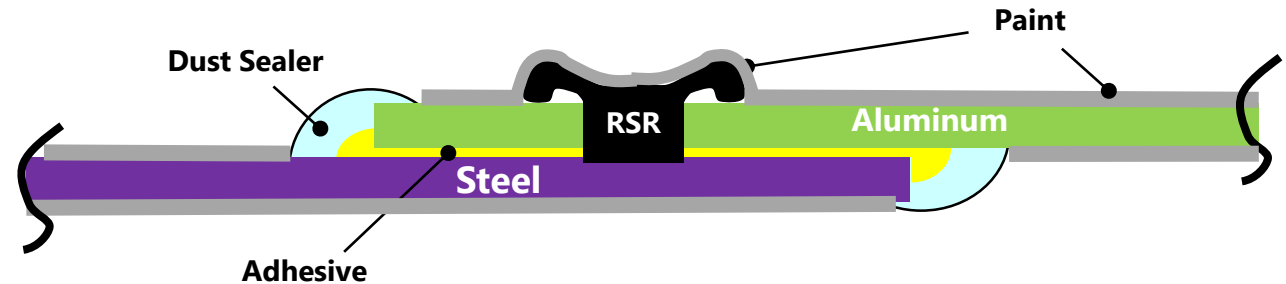
1. E-coat only (baseline)



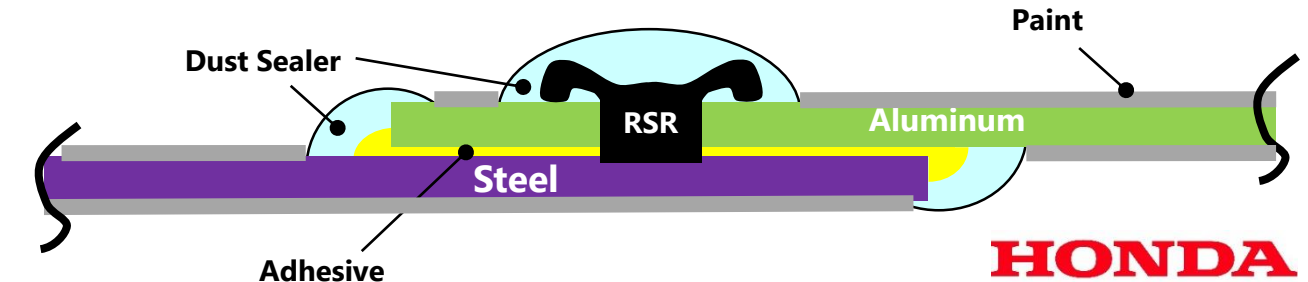
2. Edge paint



3. No edge paint, dust sealer applied to joint edges



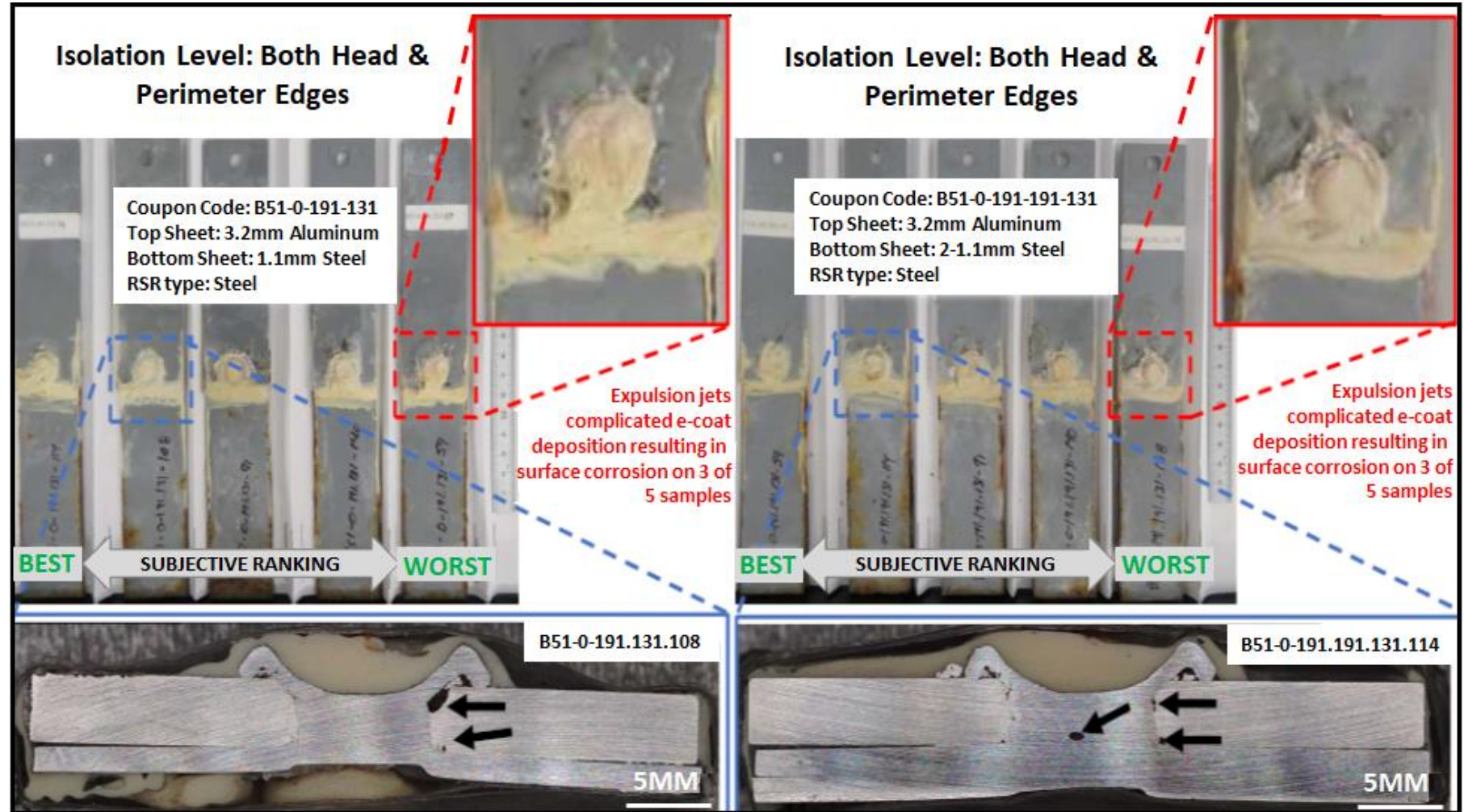
4. No edge paint, dust sealer applied to both edges and rivet head.



Honda CCT Samples After Exposure

Each test group had at least 2 samples w/o visible galvanic corrosion, showing prospect to achieve future isolation requirements

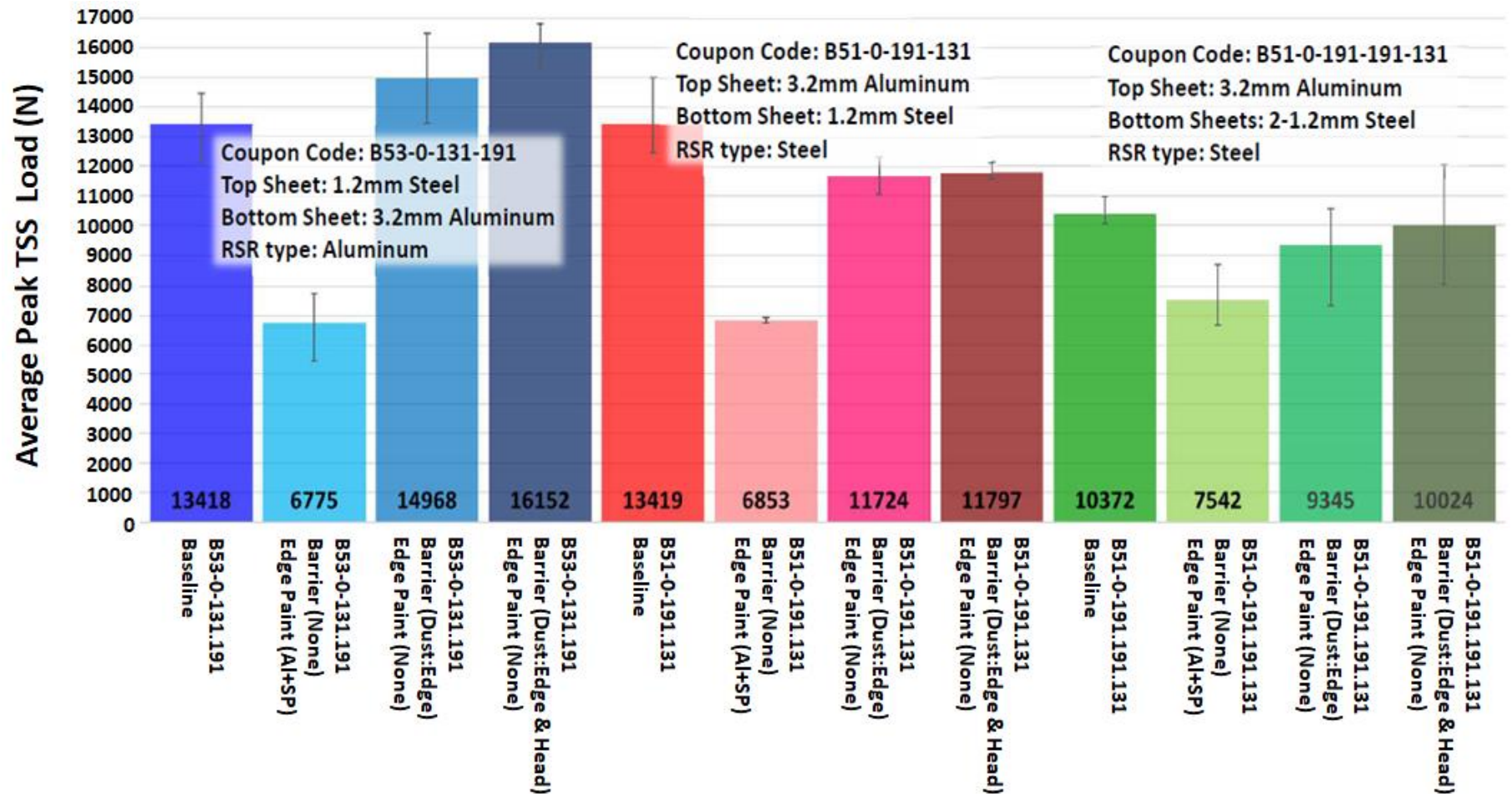
- Dust sealer on head and trim edges shows good prospect for galvanic corrosion prevention
- Rivet Head Vents (pilot hole mode only) promote expulsion jets which are risk for coating quality, galvanic corrosion
- Self-piloted samples have not been fully evaluated but generally do not display the head venting expulsion.



Honda CCT test results – TSS coupons

RSR Samples Conducted with Pilot Holes and through Structural Joint Adhesives and Various Levels of Protection

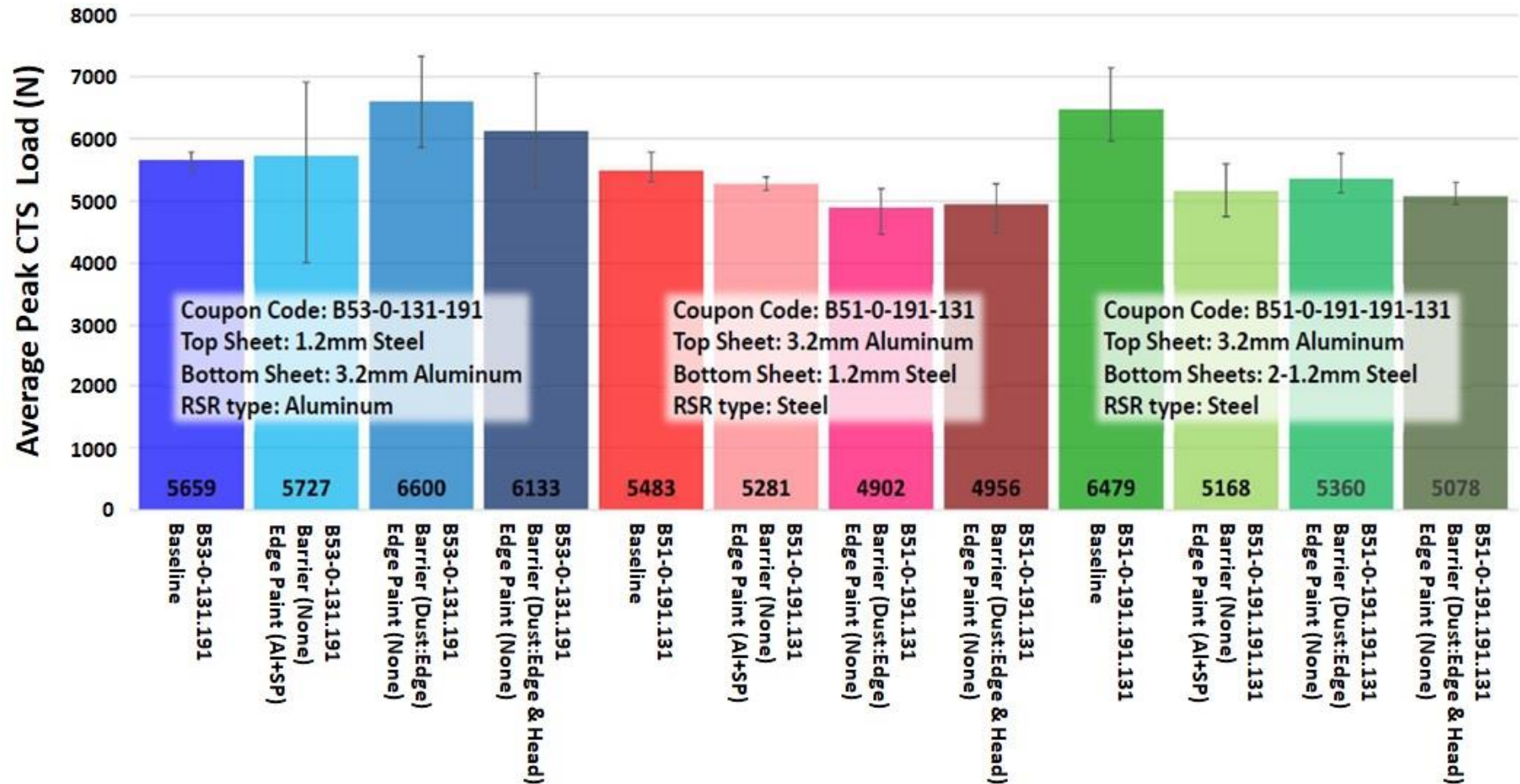
- Substantial strength reduction observed in samples w/o dust sealer on head or edge
- Samples w/ dust sealer on edges had galvanic corrosion around head
- Galvanic corrosion not observed w/ dust sealer on both head and edge
- Reductions in strength from baseline levels can be attributed to variations in joint quality and corrosion influences



Honda CCT test results – CTS coupons

RSR Samples Conducted with Pilot Holes and through Structural Joint Adhesives and Various Levels of Protection

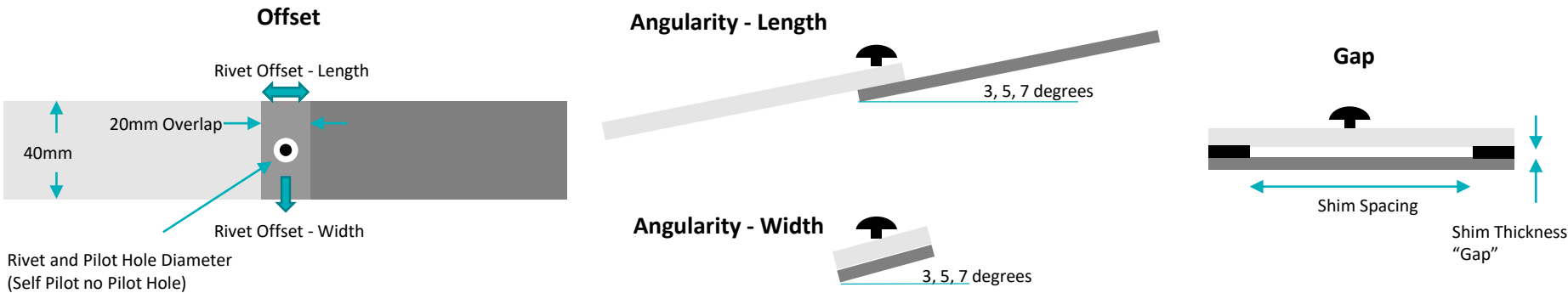
- Strength reduction differences from corrosion impacted less than in TSS
- Samples with dust sealer on edges had galvanic corrosion around head
- Galvanic corrosion not observed w/ dust sealer on both head and edge
- Reductions in strength from baseline levels can be attributed to variations in joint quality and corrosion influences



Production Condition Testing

Rivet Offset, Workpiece Angularity and Part Gap for Various Stackup Conditions

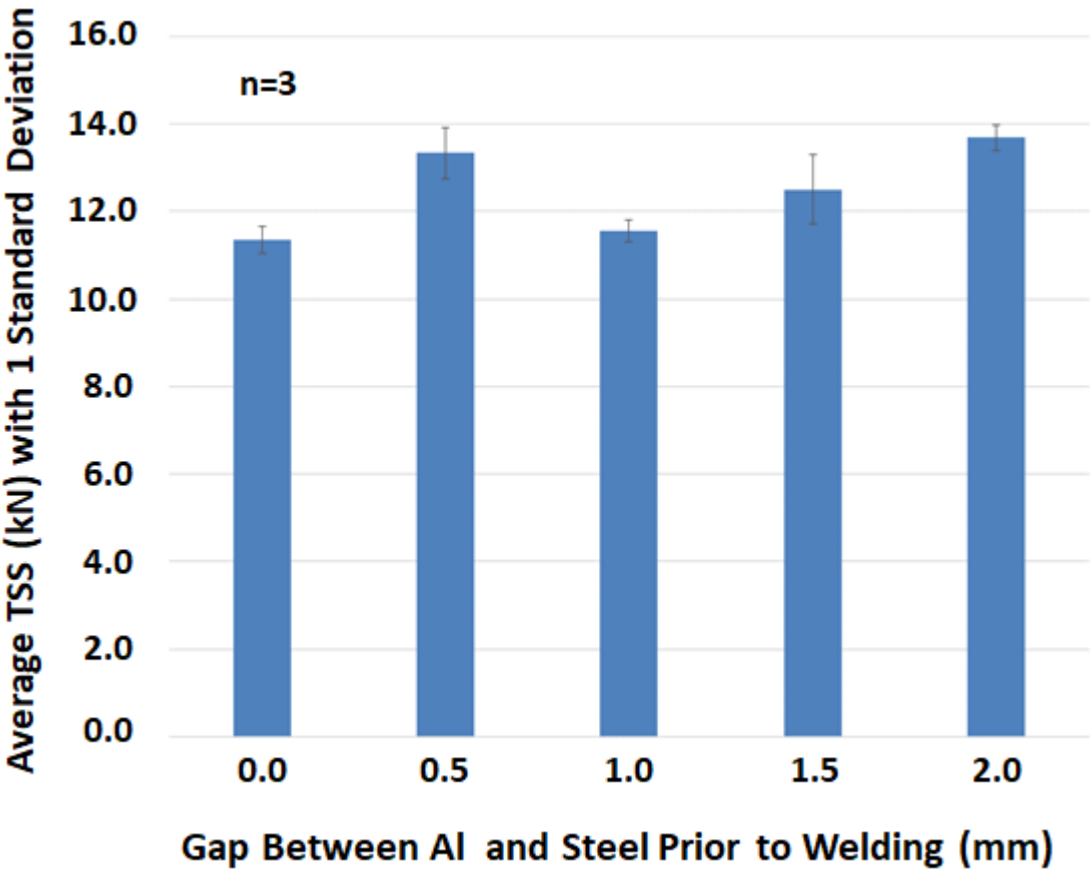
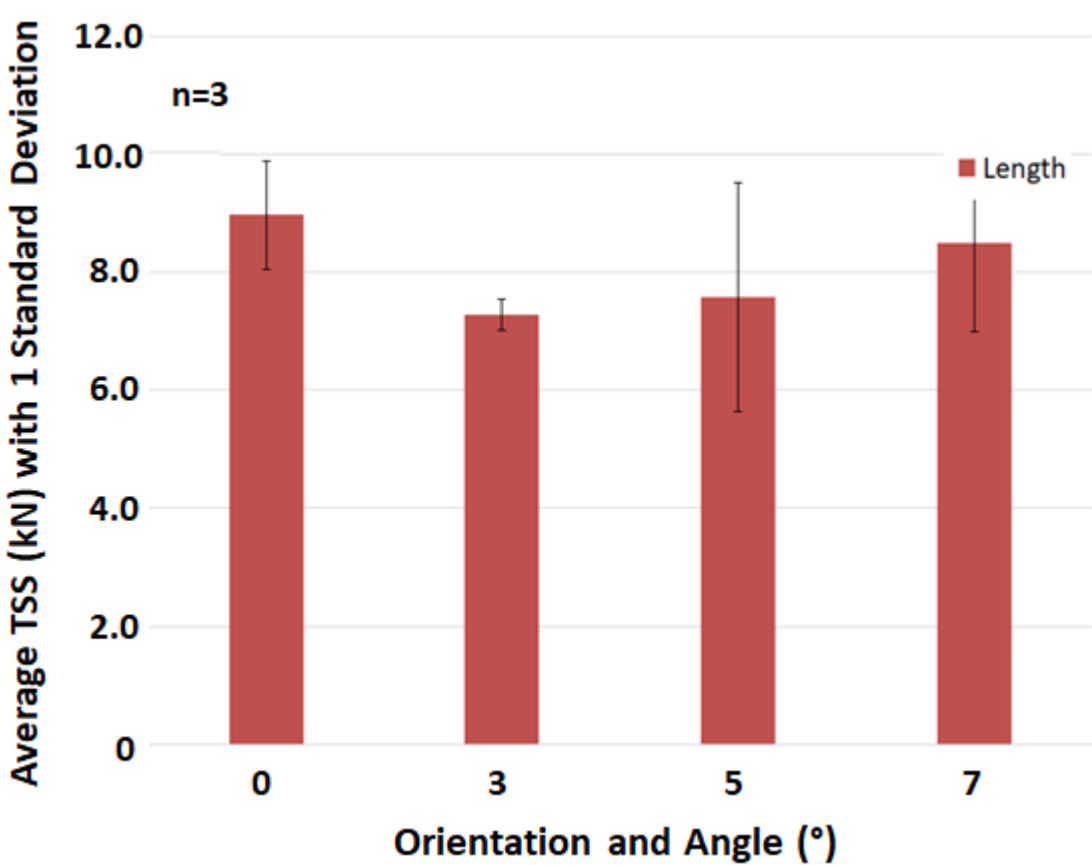
	Piloted (2mm AL) - 3 Pilot Hole Diameters	Self-Piloted (1, 3mm AL)
Rivet Offset - Width	$\frac{1}{2}(Pilot - Pin Diameter) \pm 0.5mm$	Not Applicable
Rivet Offset - Length	$\pm \left(\frac{1}{2}(Pilot - Pin Diameter) + 0.5mm \right)$	$\pm 1.0mm, \pm 2.0mm$
Angularity - Width	3°, 5°, 7° Across TSS width	
Angularity - Length	3°, 5°, 7° Along TSS length	
Gap	0.5, 1.0, 1.5, 2.0mm	
Flange Width	20mm for Piloted 2mm/3mm AL, Self Piloted 1mm AL 22, 24, 26mm for Self Piloting >3mm AL	



TSS, Weld Sectioning and CT Scans Performed for All Production Conditions

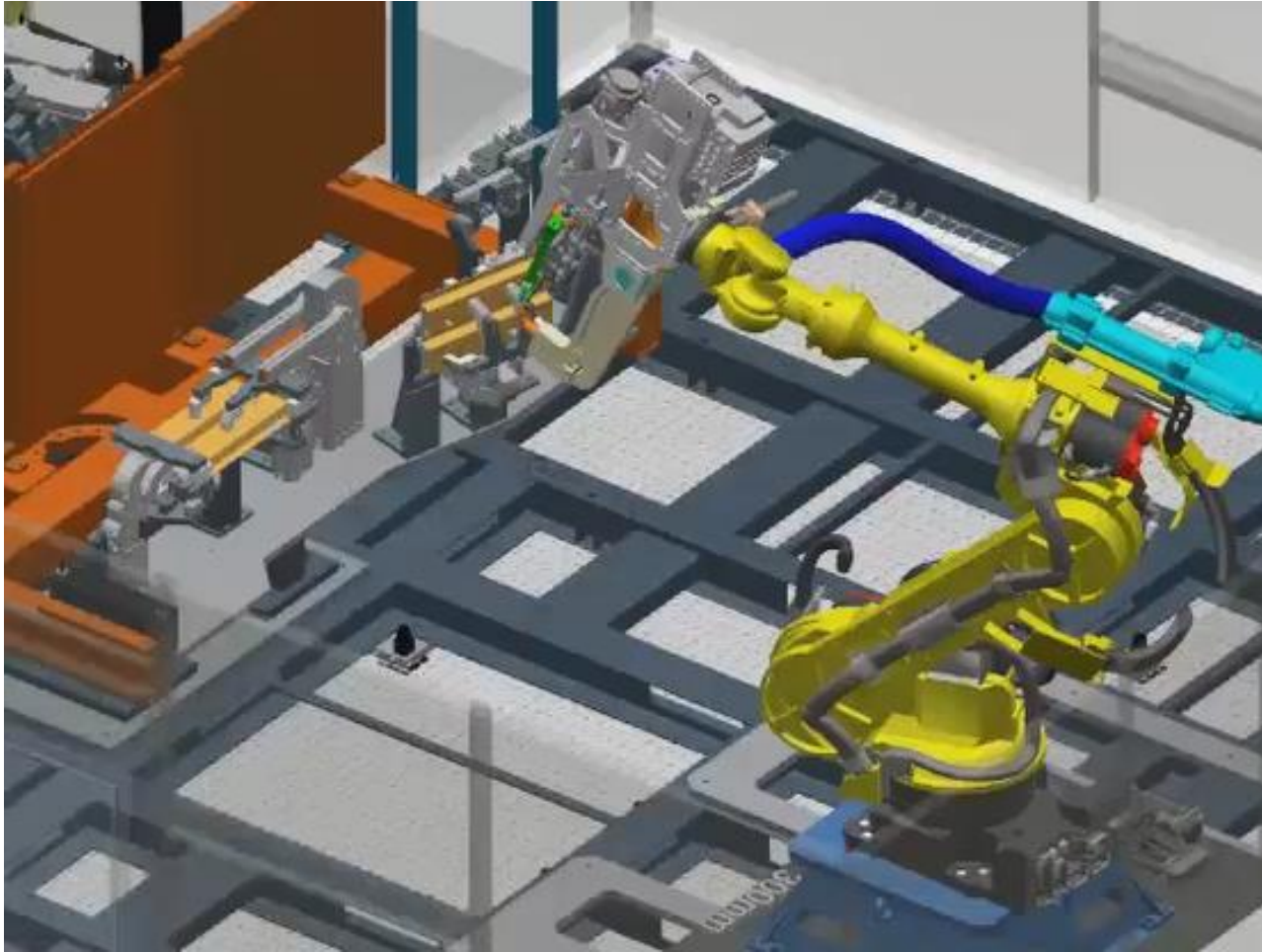
Production Condition Testing – Self Piloting

3mm Aural2-T7 aluminum and two sheets of 1.2mm 980-MPa steel



Multi-Axis Robotic RSW Demonstration

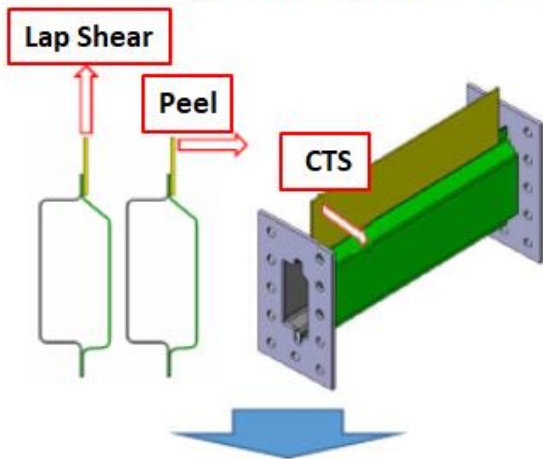
. RSR Joining Demonstrated both in Horizontal and Vertical Part Orientation



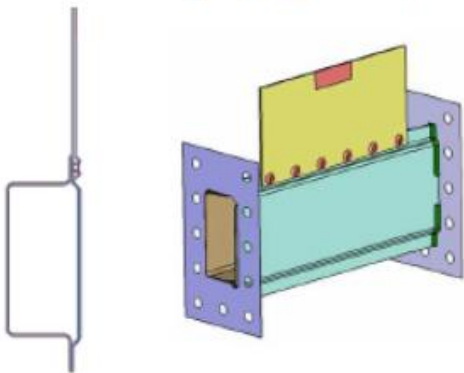
RSR Demonstration Assembly Process

First Step to Design Maturation

Initial Design Concept (Mar 2019)

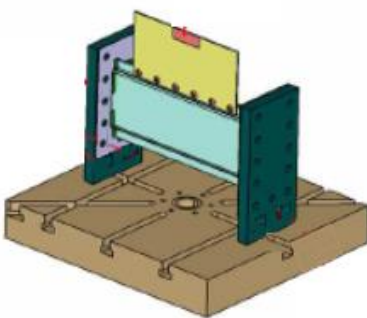


Finalized Design (Sep 2019)

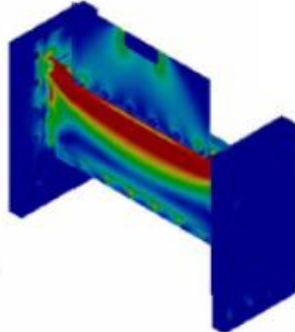


Centered Load Case

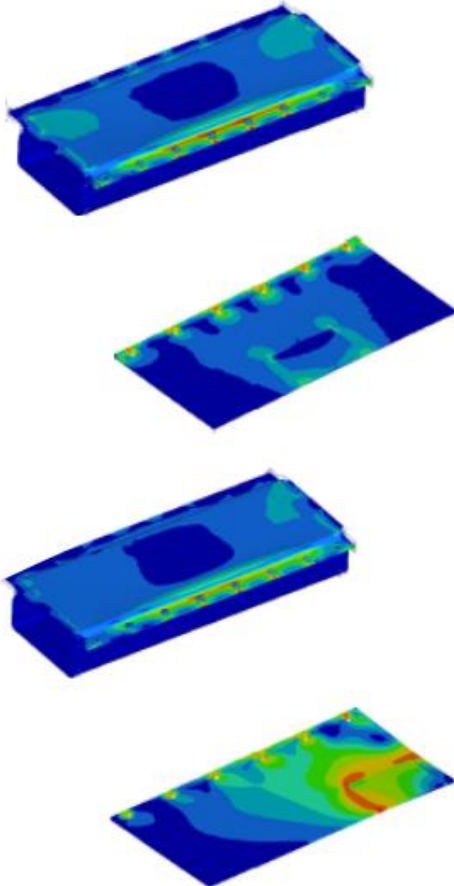
Test Setup Image



Linear Analysis

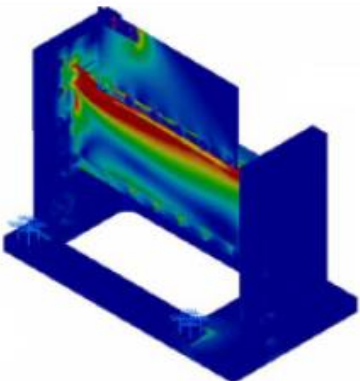
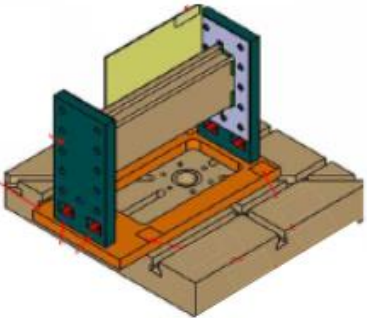


Non-Linear Analysis



Basic test frame setup used to conduct preliminary linear analysis, affirming stress flow patterns to validate fastener load trends. Non-linear analysis used to predict functional response levels and potential failure patterns.

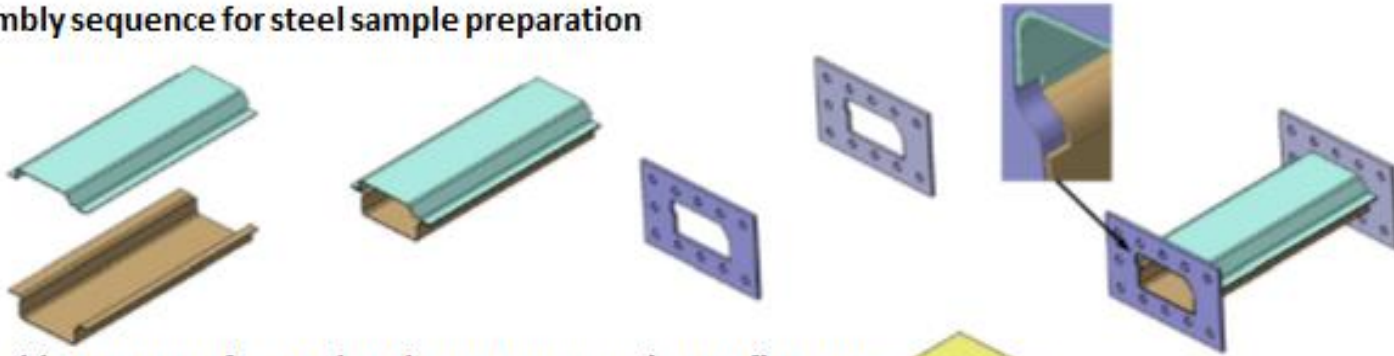
Offset Load Case



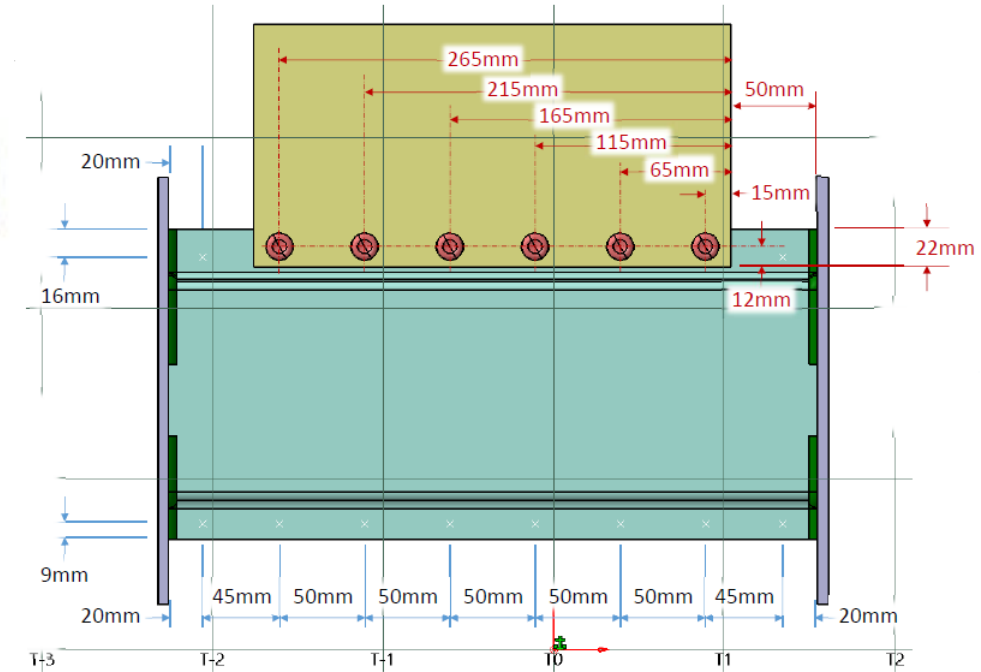
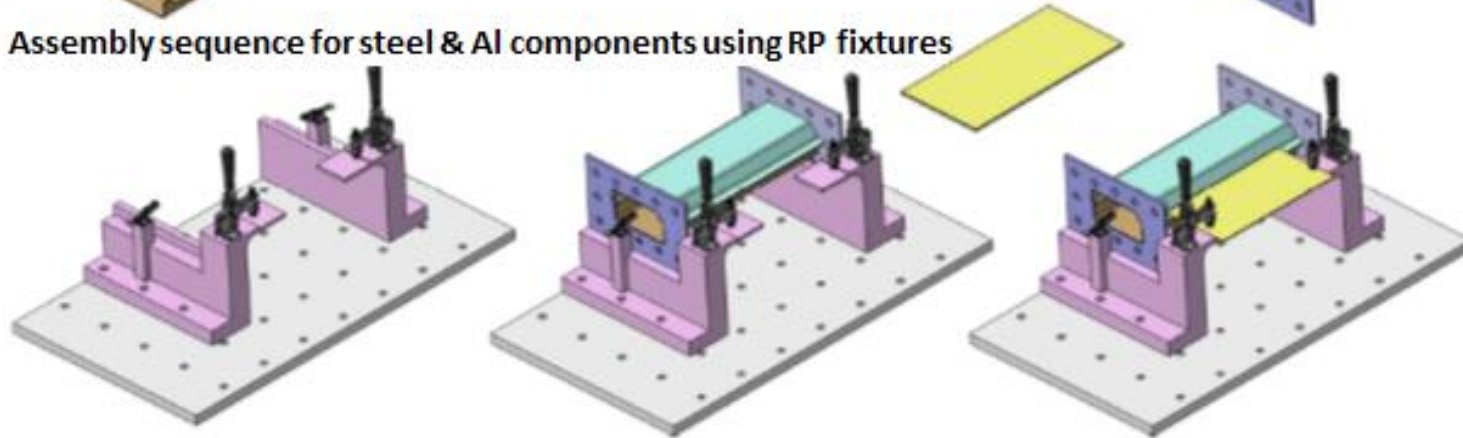
Demonstration Assembly Manufacturing Sequences

Demonstrator Contains both 2T Steel Resistance Spot Welds and 3T Aluminum to Steel RSR Joints Manufactured with Same Welding Gun

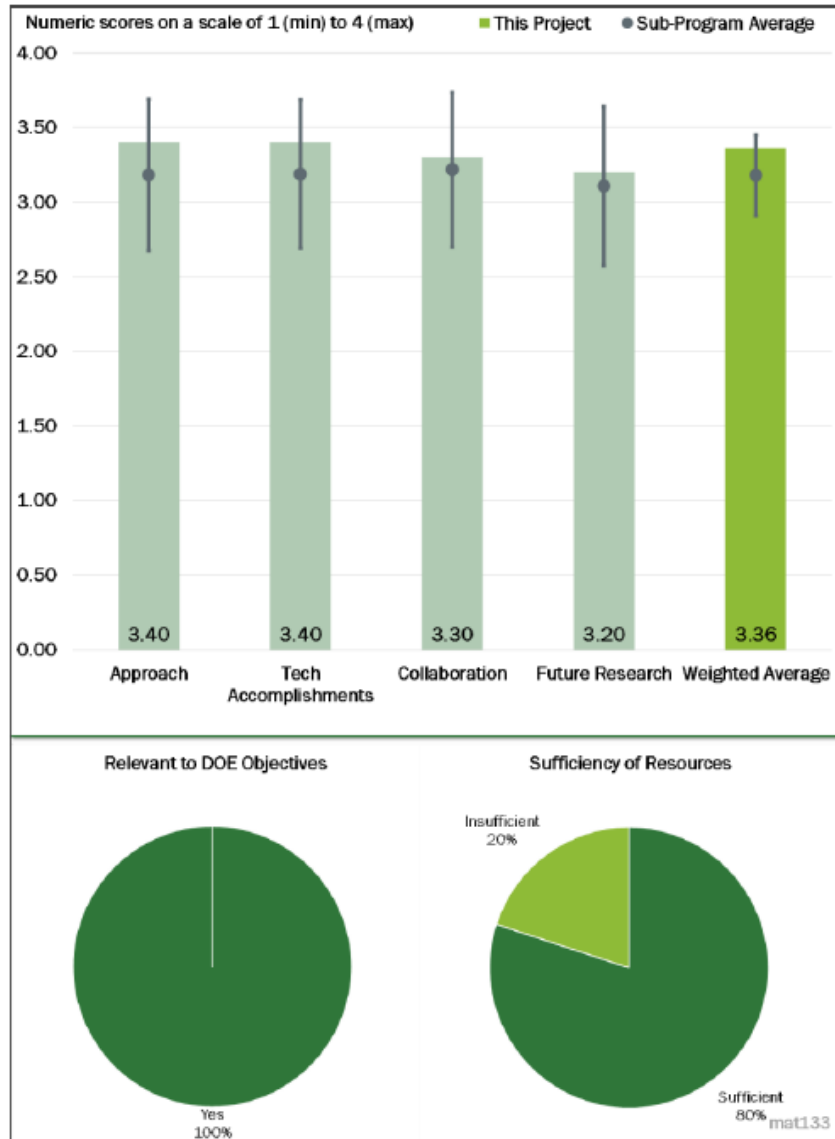
Assembly sequence for steel sample preparation



Assembly sequence for steel & Al components using RP fixtures



Responses to Prior-Year Comments



- Comment: Coupon orientation highlights a need to investigate the differences in electrochemical potential; fundamental reason for differences in corrosion with orientation. Response: Additional testing by OSU to explore the orientation effect and electrochemical potential studies has been completed.
- Comment: Thermal expansion coefficients of the dissimilar materials Response: Corrosion samples evaluated by Honda were thermally treated during e-coat. Joining technologies (SPR, FDS) in automotive applications currently so focus was on corrosion and industrialization
- Comment: Allows use of ... resistance spot weld equipment, thus substantially improving the chances of ... being implemented into high volume manufacturing operations in the near future.
- Comment: Production condition accomplishments should contribute significantly to the success of commercializing the joining method and process



Collaboration and Coordination with Other Institutions



Arconic will oversee project management. Arconic will produce the RSR samples for mechanical and corrosion testing and later produce the demonstration assemblies. Arconic will integrate the rivet delivery system to a robotic pilot cell to demonstrate production capability. Arconic will explore production variations such as joint gaps, angularity, flange length variations and stack thickness variations.



Honda will develop specification requirements for related coupon testing that will be conducted by Honda, industry, and the Ohio State University. Honda will also provide support with specification development for the joining process and equipment requirements. Honda will judge the functional performance of the component in comparison to the baseline hot stamped UHSS application.



The Ohio State University will characterize and quantify the galvanic corrosion resistance of RSR joints of aluminum to steel and aluminum to CFRP and the ability of adhesives, pre joining surface coatings, and e-coat/paint/sealant packages to protect the RSR joint against galvanic corrosion.



Remaining Challenges and Barriers

- Corrosion behavior of other multi-material joining technologies are well understood. These technologies are typically done at room temperature (i.e. mechanical fasteners) which do not alter the sensitivity of the base aluminum. RSR needs to have the baseline established, and if necessary, improve the corrosion performance to meet industry needs.
- Confidence in the RSR process robustness must be established for production applications. Electrode life and electrodes must be in line with existing tip-dressing frequency to be viable.
- Confidence in the RSR process to meet target strengths with variations in the processing conditions (gap, angularity, offset, flange width) must be demonstrated to prove production feasibility.
- The ability to self-pilot through aluminum materials thicker than 2.0mm with acceptable insertion times will increase the applicability of the RSR process.
- Confidence in the RSR process for high-volume manufacturing. RSR has only been demonstrated on a stationary pilot station and on small scale demonstration articles.

We will address these items in our future work

Proposed Future Research

FY20 proposed Work will Include:

1. Complete corrosion testing for at OSU and Honda
2. Assess production galvanic corrosion mitigation strategies to improve corrosion performance
3. Manufacture demonstrator parts and assemblies
4. Test demonstrator assemblies
5. Final Reporting

Any proposed future work is subject to change based on funding levels.

Summary

1. OSU has completed testing under the ASTM B117, ASTM G85-A2, and CCT-1 methods, and observed the severity of corrosion varied among different material combinations. Orientation can influence the aggressiveness of the galvanic corrosion pitting so special care must be noted when comparing technologies.
2. Honda's CCT testing showed for both aluminum and steel RSR samples without head or edge protection displayed a wider range in functionality and had clear signs of galvanic corrosion. Samples with edge protection only at the multi-material interface displayed galvanic corrosion around the rivet head. Samples with both head and edge protection had no immediate signs of galvanic corrosion and displayed similar strength performance to the controls.
3. Production conditions including part angularity, gaps, rivet offset, flange overlap, and pilot hole diameter were evaluated for both piloted and self-piloted applications, showing less than 25% strength decreases over a wide process range.
4. The final integration of the RSR rivet delivery system into an automated robotic cell was completed by AFS and its integrator CenterLine, Ltd. The system was evaluated for feed reliability, achieving several thousand cycles without faulting. RSR welding trials were completed on a double hat section in both horizontal and vertical positions.
5. Honda completed the initial design of the demonstrator and assembly tools/sequence. Tool design, manufacturing sequencing, fabrication, and component assembly is targeted in 2020.

Backup Slides

Project ID: MAT133



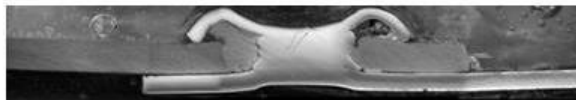
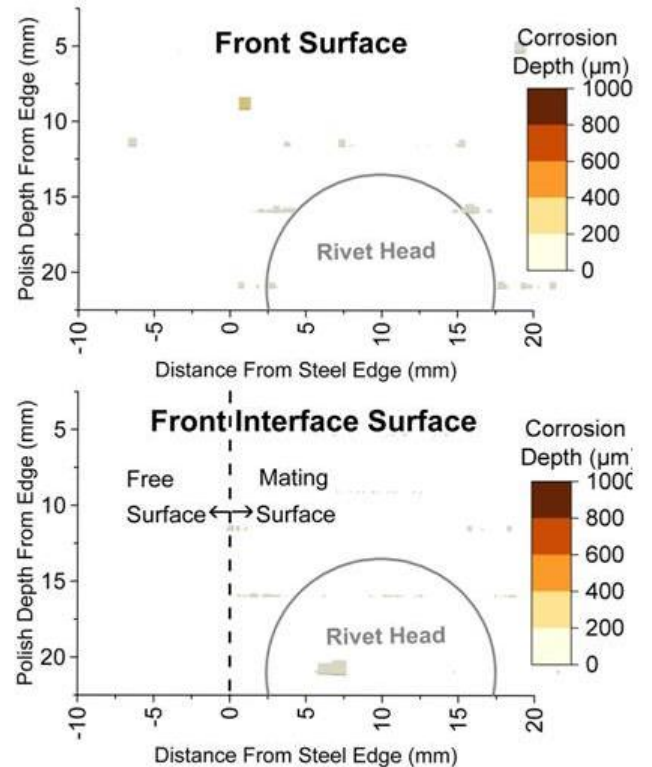
ARCONIC



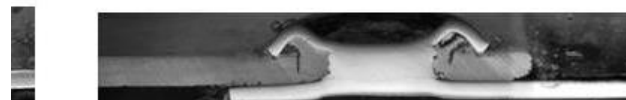
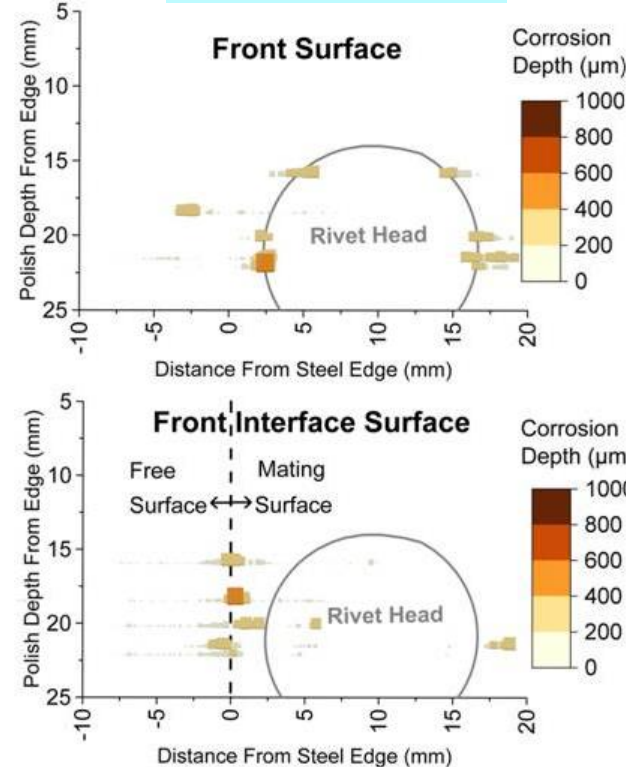
Technical Accomplishments and Progress

AA5754-O joined to 590MPa steel via RSR after 32.4 days exposure

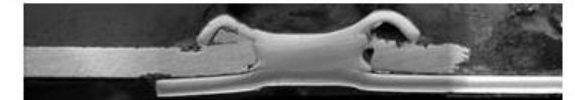
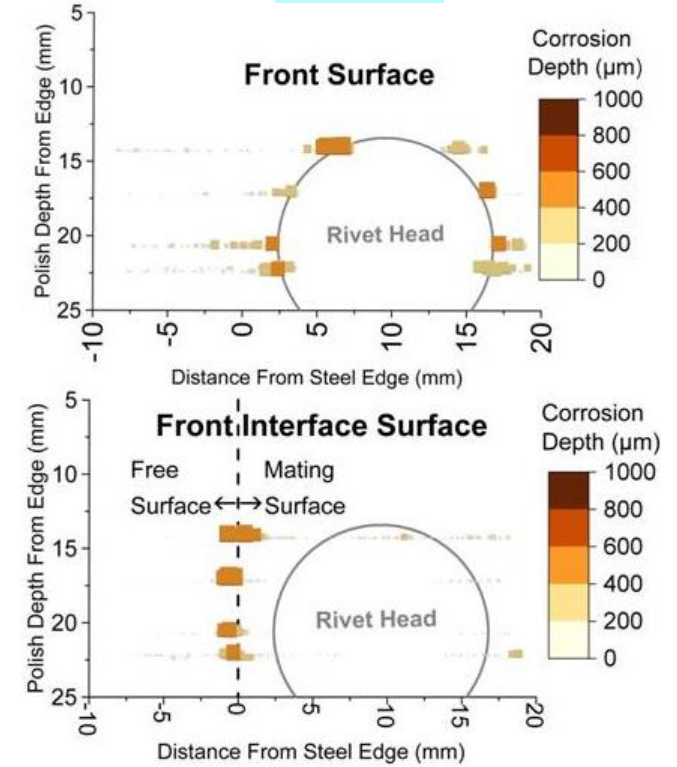
ASTM B117



ASTM G85-A2



CCT-1



Production Condition Testing – Self Piloting

1.0mm MMHF-T4 aluminum and two sheets of 1.2mm 980-MPa steel

